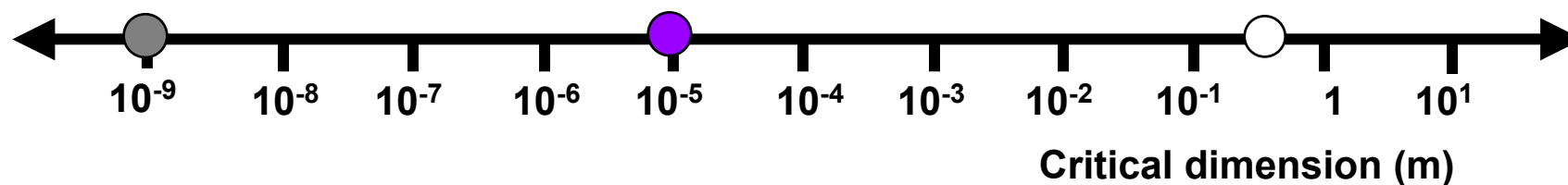
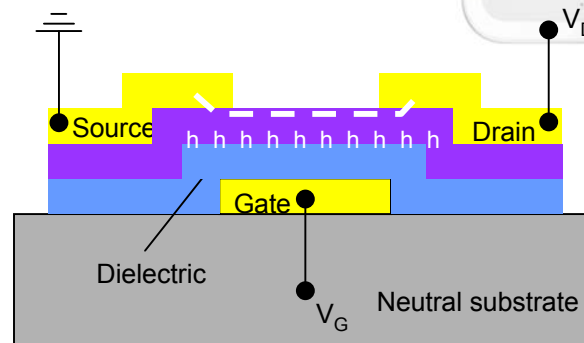
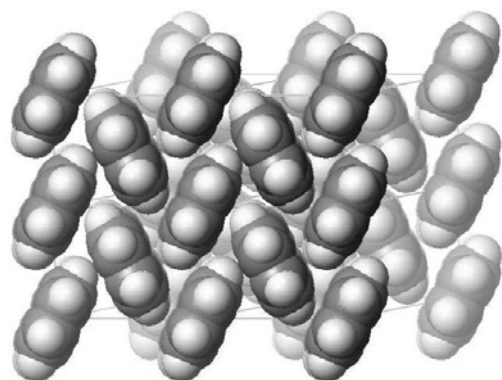


Organic Electronics

(Course Number 300442) Spring 2006

Introduction to Organic Electronics

Instructor: Dr. Dietmar Knipp



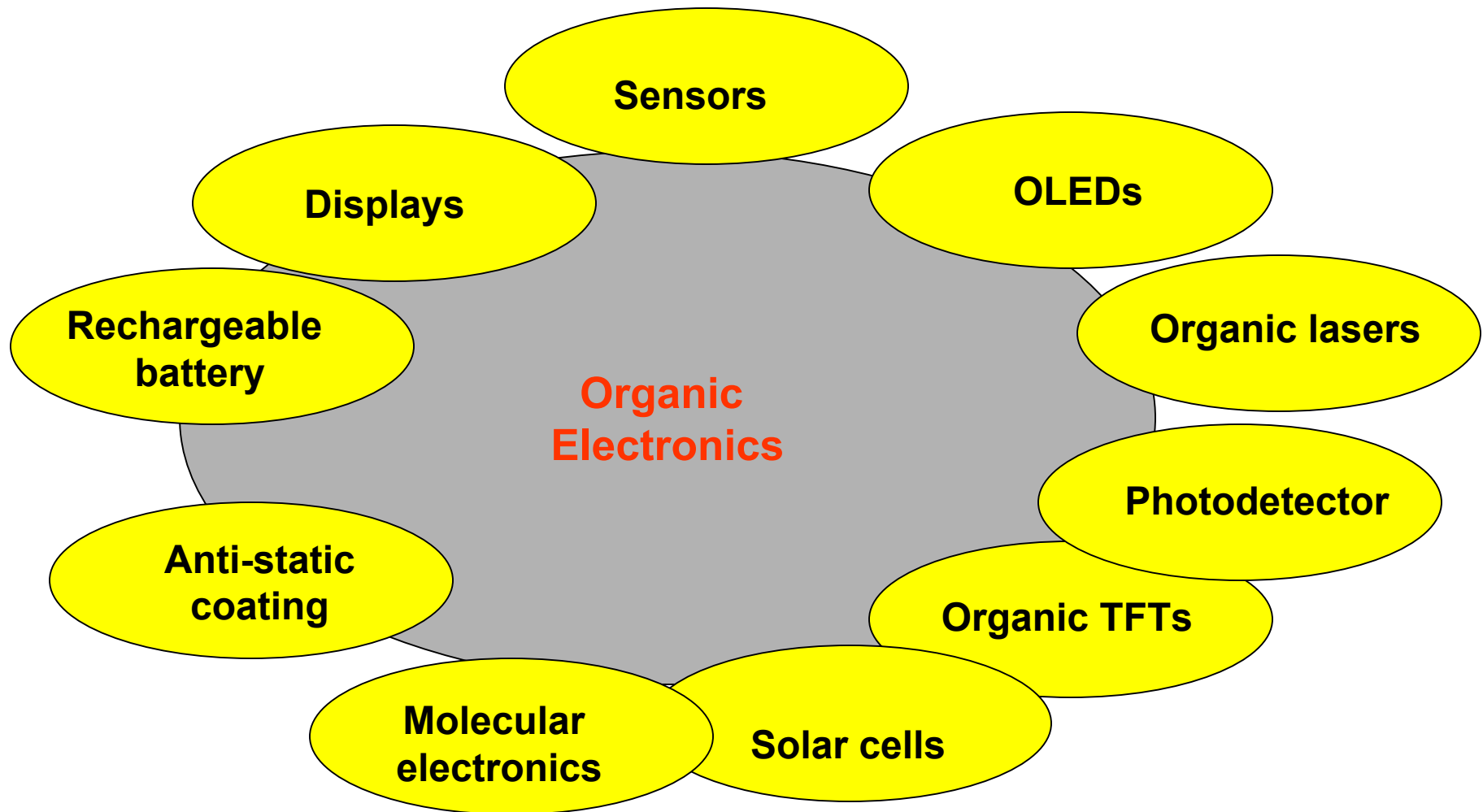
Organic Electronics

1 Introduction to Organic Electronics

- 1.1 Organic electronics and its application areas
- 1.2 A little bit of history in organic electronics
- 1.3 Advantages and Disadvantages of organic electronic materials
- 1.4 Organic and polymeric displays
- 1.5 Color Vision and Color perception
- 1.6 Organic light emitting diodes (small molecule devices)
- 1.7 Polymer light emitting diodes (polymer devices)
- 1.8 Passive versus Active Matrix Display Addressing
- 1.9 Overview of thin film transistor technologies
- 1.10 Summary

References

1.1 Organic electronics and its application areas



1.2 A little bit of history in organic electronics

- 1950's: Work on crystalline organics materials starts.
(At that time organic crystal where considered to be an alternative to silicon)
- 1970's: Organic photoconductors (xerography)
- 1980's: Organic non-linear optical materials
- 1987: Kodak group published the first efficient organic light emitting device (OLED)
- Results on the first organic transistor where published.
- 1990's: Friend group (Cambridge University) published the first results on polymer light emitting diodes.
- 2000: Noble price in chemistry for the "discovering and development of conductive polymers" (Heeger, MacDiarmid and Shirakawa)
- 2000's: Organic solar cells with efficiencies of >5% were realized.

1.2 A little bit of history in organic electronics



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Nobel Prize in Chemistry for 2000

Alan J. Heeger, University of California at Santa Barbara, USA,

Alan G. MacDiarmid, University of Pennsylvania, Philadelphia, USA,

Hideki Shirakawa, University of Tsukuba, Japan

"for the discovery and development of conductive polymers"

Plastic that conducts electricity

We have been taught that plastics, unlike metals, do not conduct electricity. In fact plastic is used as insulation round the copper wires in ordinary electric cables. Yet this year's Nobel Laureates in Chemistry are being rewarded for their revolutionary discovery that plastic can, after certain modifications, be made electrically conductive. Plastics are polymers, molecules that repeat their structure regularly in long chains. For a polymer to be able to conduct electric current it must consist alternately of single and double bonds between the carbon atoms. It must also be "doped", which means that electrons are removed (through oxidation) or introduced (through reduction). These "holes" or extra electrons can move along the molecule - it becomes electrically conductive. Heeger, MacDiarmid and Shirakawa made their seminal findings at the end of the 1970s and have subsequently developed conductive polymers into a research field of great importance for chemists as well as physicists. The area has also yielded important practical applications. Conductive plastics are used in, or being developed industrially for, e.g. anti-static substances for photographic film, shields for computer screen against electromagnetic radiation and for "smart" windows (that can exclude sunlight). In addition, semi-conductive polymers have recently been developed in light-emitting diodes, solar cells and as displays in mobile telephones and mini-format television screens. Research on conductive polymers is also closely related to the rapid development in molecular electronics. In the future we will be able to produce transistors and other electronic components consisting of individual molecules - which will dramatically increase the speed and reduce the size of our computers. A computer corresponding to what we now carry around in our bags would suddenly fit inside a watch.

Ref.: <http://nobelprize.org/index.html>

1.3 Advantages and Disadvantages of organic electronic materials

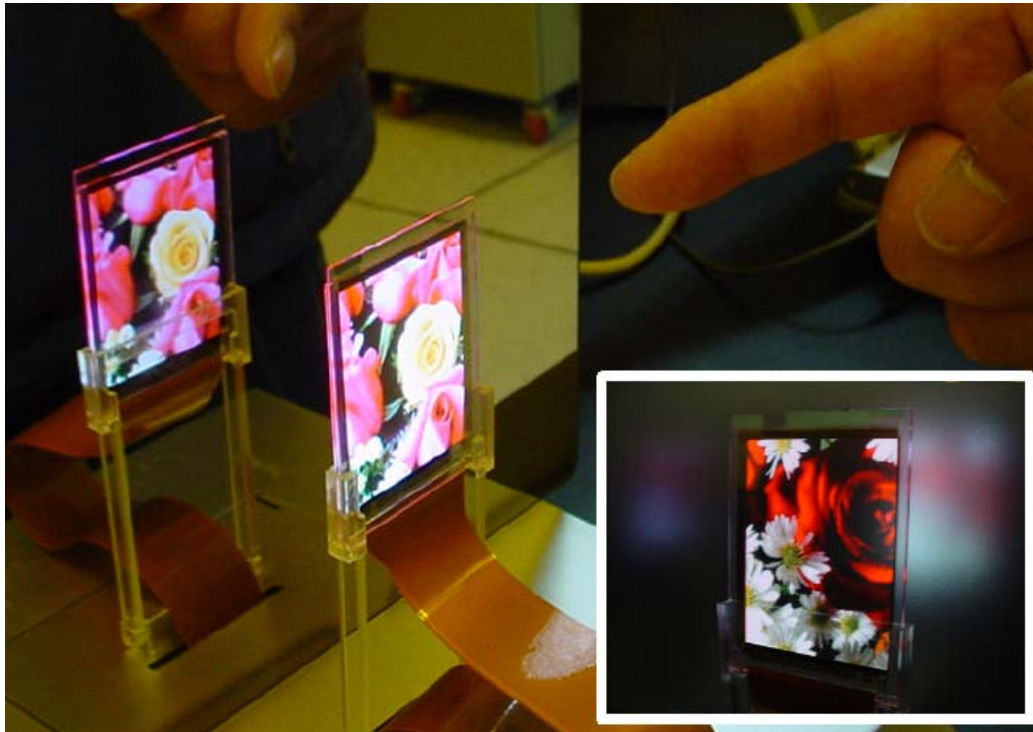
Attractive due to:

- Technology is compatible with Large area processes (low cost)
- Low temperature processing (low cost)
- Molecules and polymers can be tailored for specific electronic or optical properties
- Compatible with inorganic semiconductors

Existing problems:

- Low carrier mobility
- Electronic and optical stability of the materials
- Processing is incompatible with classical processing in semiconductor industry.

1.4 Organic and polymeric displays



Demand on Displays:

- Low cost
- Large area
- Low power consumption
- Low weight
- Flexible displays

Photo of high resolution organic LED based displays for mobile applications. Ref.: Samsung

1.4 Organic and polymeric displays

The perfect display!



Vision of a foldable
and bendable display.
[Ref. Universal Display
Corporation, UDC]

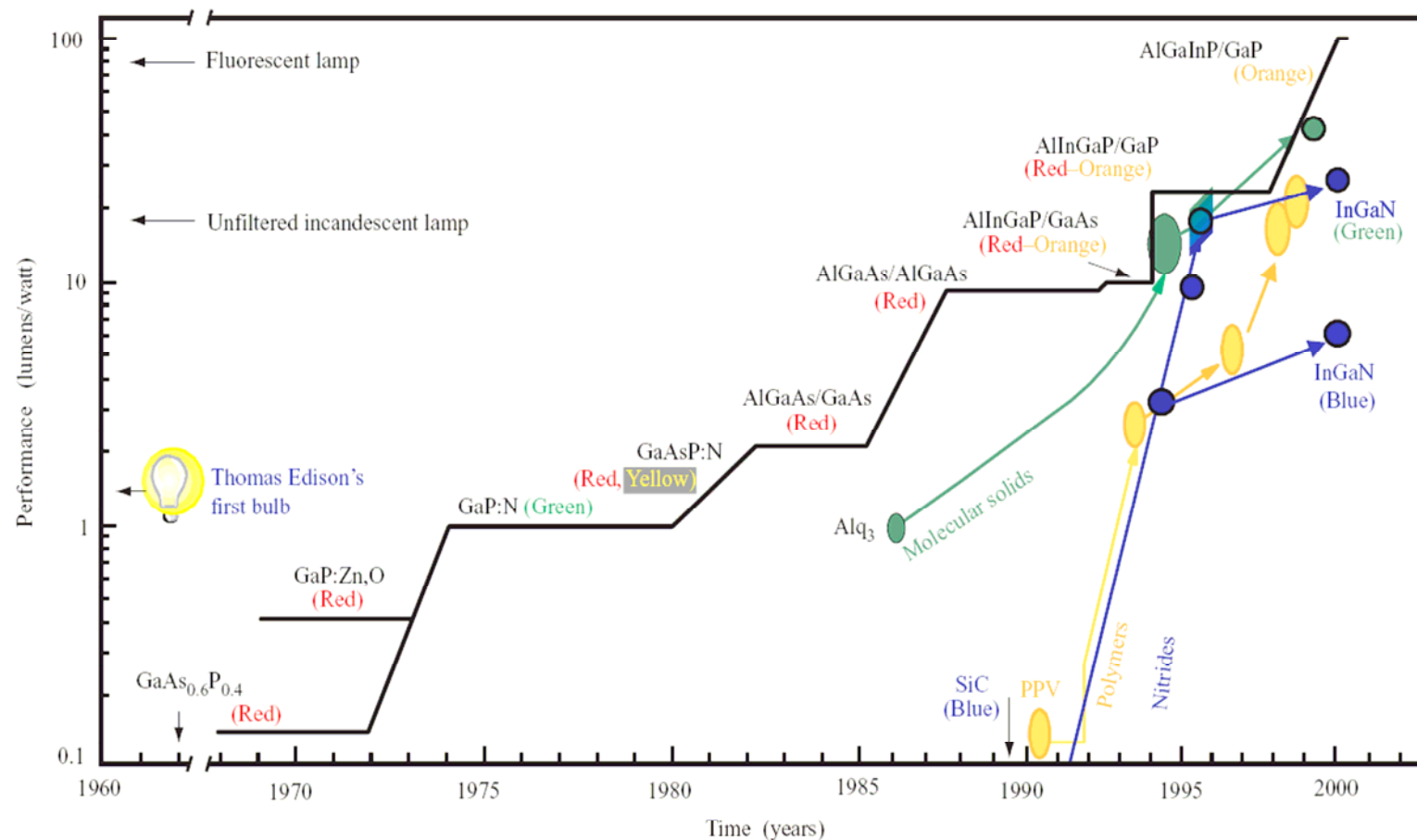
Organic or polymeric light emitting diodes (LEDs) are of interest for displays.

The power consumption of oLED displays is lower than the consumption of LCD displays.

For high resolution displays active matrix addressing of displays (LED and LCD) is needed. Active matrix addressing is realized by thin film transistors (TFTs).

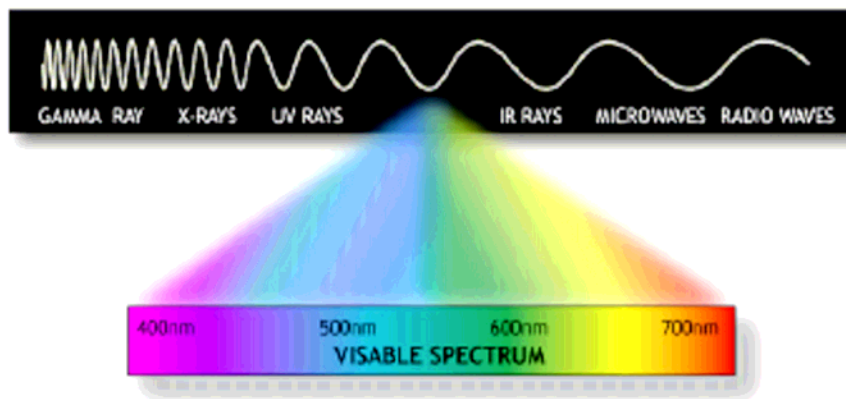
1.4 Organic and polymeric displays

Comparison of light emitting diode technologies



Ref.: J. M. Shaw and P. F. Seidler, IBM

1.5 Color Vision and Color perception

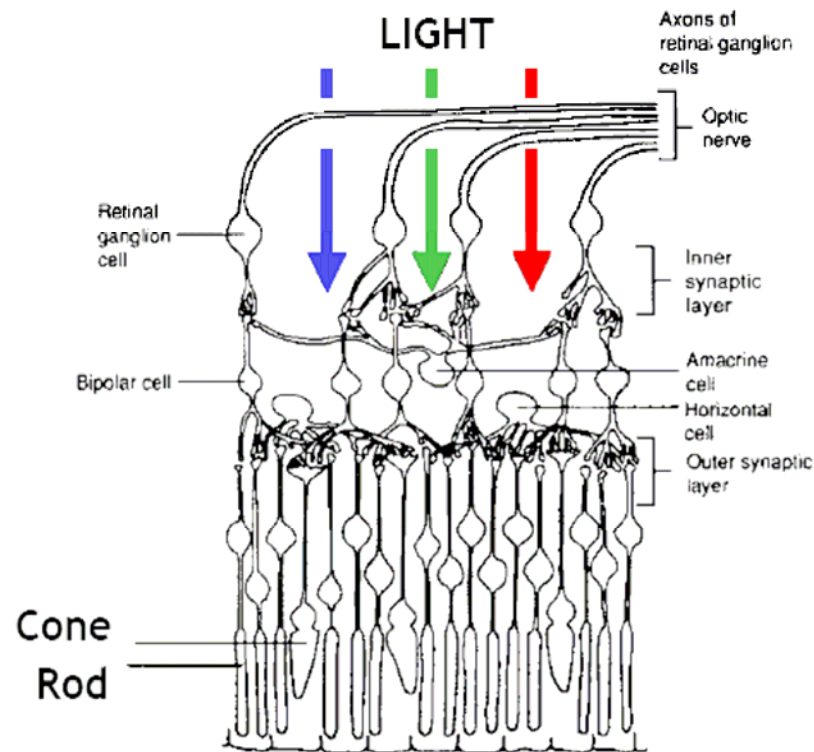


$$E = E_2 - E_1 = hf = \frac{hc}{\lambda}$$

Photon energy

The interaction of light and matter in the form of absorption and emission requires a transition from one discrete energy level to another energy level. The frequency and the wavelength of the emitted or absorbed photon is related to the difference in energy E , between the two energetic states, where h is the Planck constant $h=6.626 \times 10^{-34}\text{J}$, f is the frequency and λ is wavelength of the absorbed or emitted light.

1.5 Color Vision and Color perception

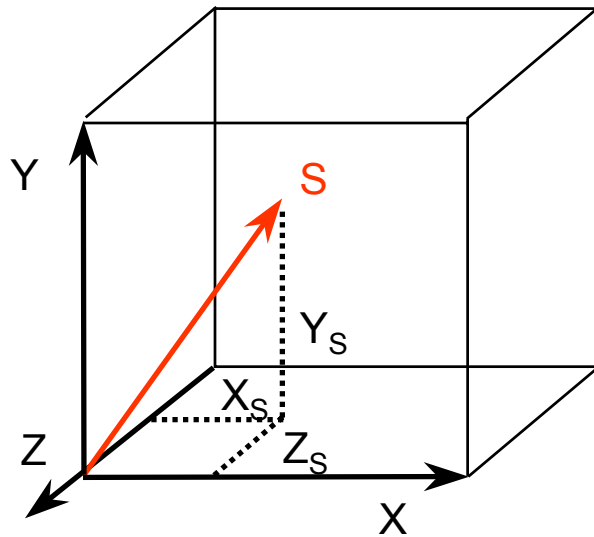


The Neural Structure of the Retina

- A color is defined by the capabilities of the human eye. The human color perception has to be considered when designing a display.
- The human color perception is non linear (in the physical sense).

Ref.: V.Bulović, Organic Opto-Electronics, MIT

1.5 Color Vision and Color perception



Representation of colors in the XYZ color space.

$$X_S = k \cdot \int_{380nm}^{780nm} S(\lambda) \cdot r(\lambda) \cdot x_S(\lambda) d\lambda$$

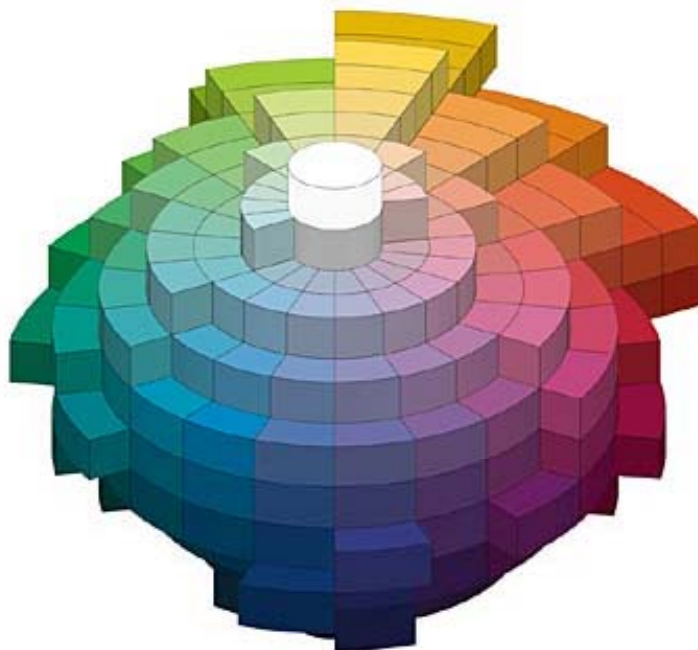
$$Y_S = k \cdot \int_{380nm}^{780nm} S(\lambda) \cdot r(\lambda) \cdot y_S(\lambda) d\lambda$$

$$Z_S = k \cdot \int_{380nm}^{780nm} S(\lambda) \cdot r(\lambda) \cdot z_S(\lambda) d\lambda$$

$S(\lambda)$: spectrum of the light source,
 $R(\lambda)$: reflection of an object,
 $x(\lambda), y(\lambda), z(\lambda)$: color matching functions,
 representing the sensitivity of the
 human eye

Each color can be described as a vector!

1.5 Color Vision and Color perception



Dimensions of the color
space: hue, chroma, value

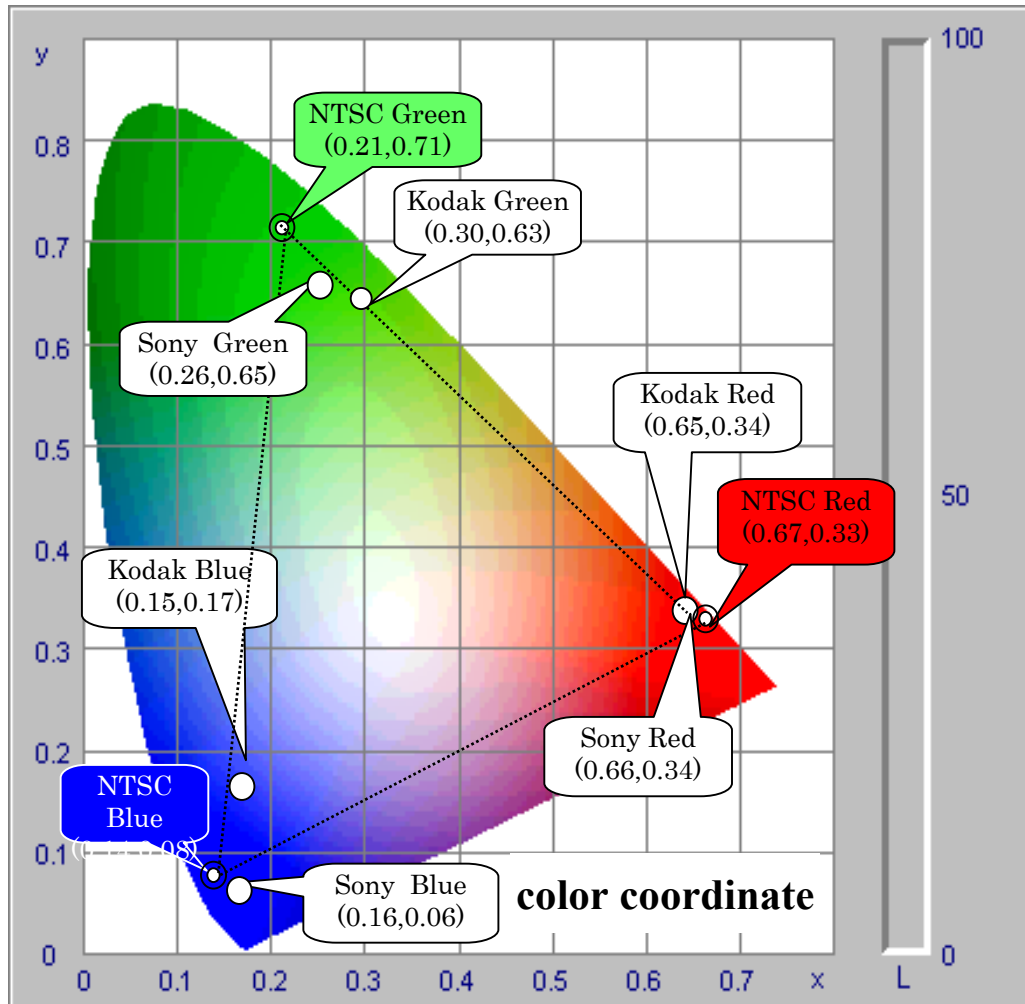
200 Hue levels

20 Saturation levels

500 Chroma levels

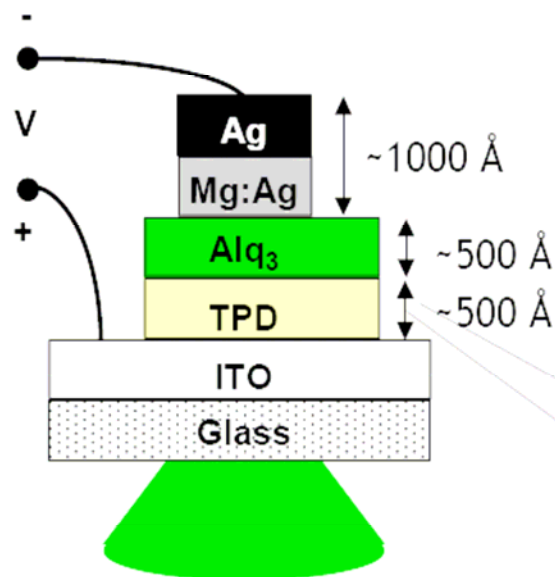
1.5 Color Vision and Color perception

Status of Active Matrix Organic Light Emitting Device (AMOLED) Displays



Mapping of the RGB color space and the color space of the display. (Gamut mapping)

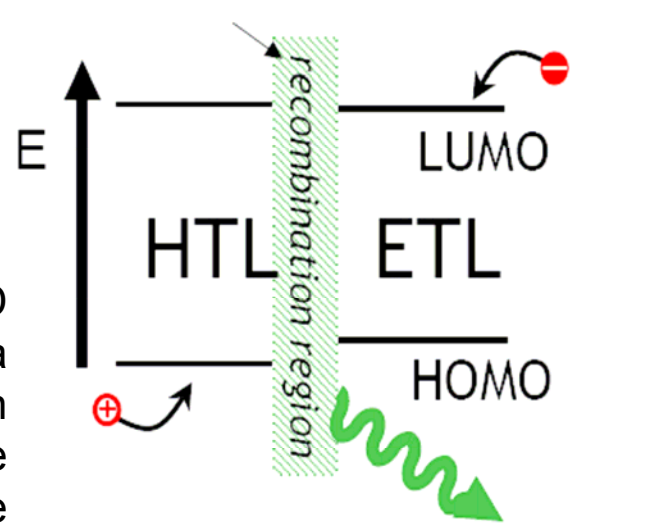
1.6 Organic light emitting diodes (small molecule devices)



The simplest possible organic LED consists of hetero-interface between a hole-conducting material (TPD) and an electron conducting material (Alq_3). The light emission takes place at the interface between Alq_3 and TPD.

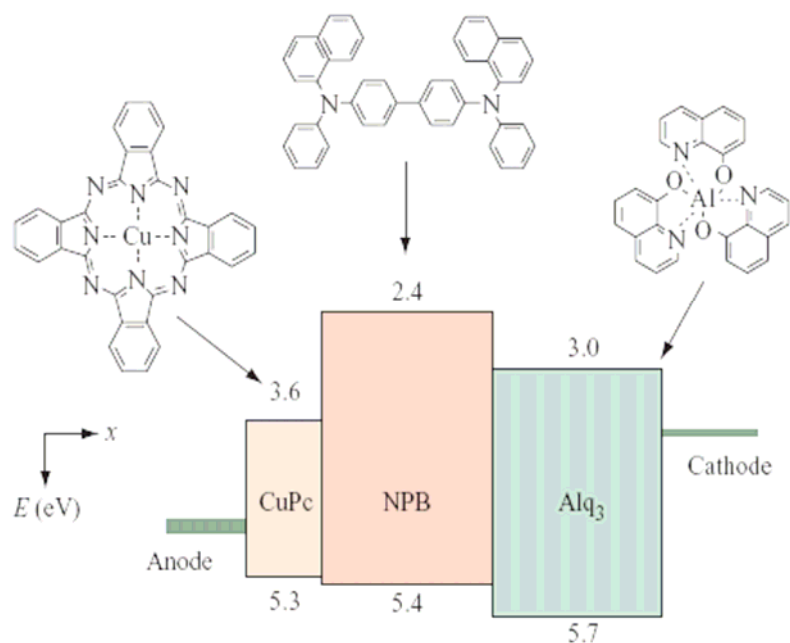
Electro luminescence requires several steps, including the injection of charges (electrons and holes) in the device, the transport of the charges in the films, confinement of charges, and radiative recombination of charge carriers inside an organic layer with an energy gap suitable for yielding visible light output.

Solution: Separately optimize the individual steps by using a multilayer light-emitting devices (LEDs).



Ref.: V.Bulović, Organic Opto-Electronics, MIT

1.6 Organic light emitting diodes (small molecule devices)



Optimized device structure:

Copper phthalocyanine (CuPc) as the buffer and hole-injection layer,

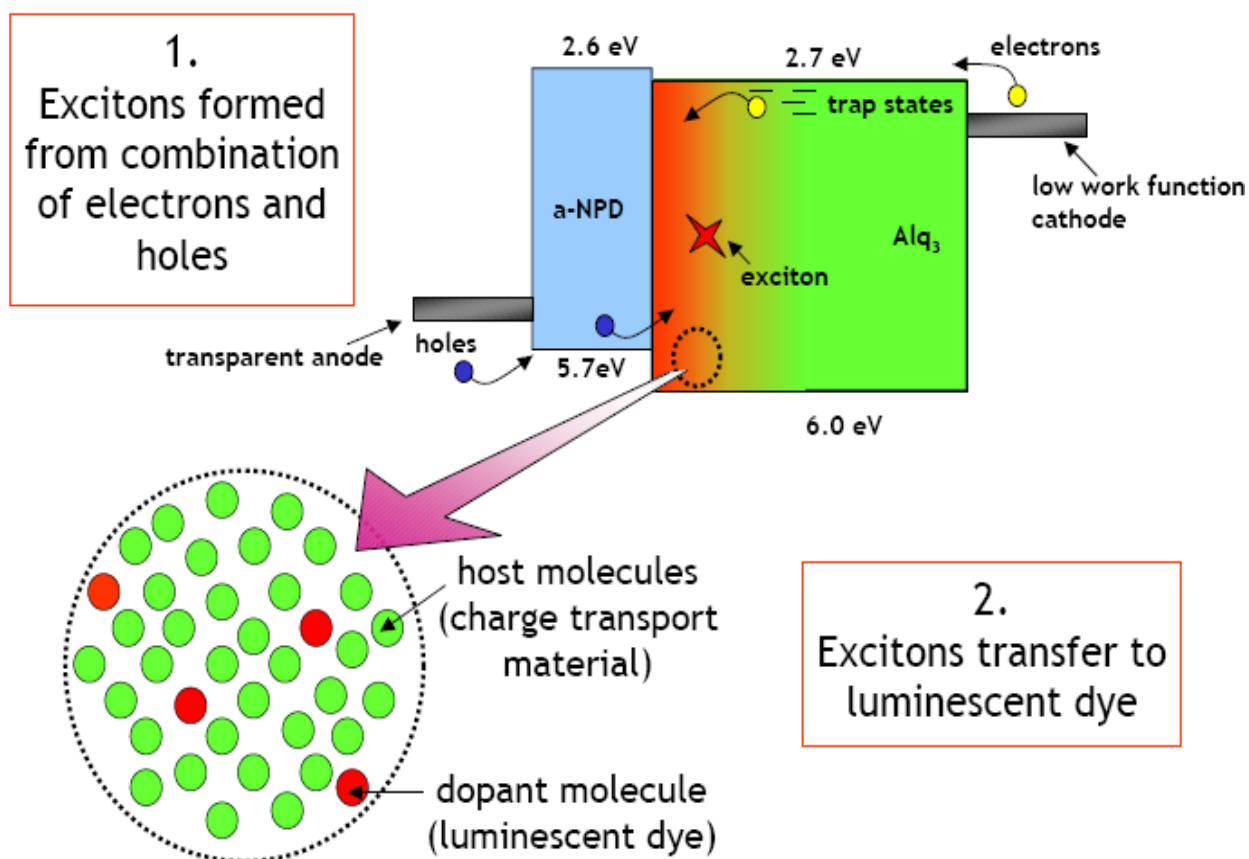
NPB as the hole transport layer

Alq₃ as the electron transport and emitting layer.

Schematic energy-level diagram and chemical structures of the organic materials used for the OLEDs.
Ref.: Riess group, IBM Zuerich

1.6 Organic light emitting diodes (small molecule devices)

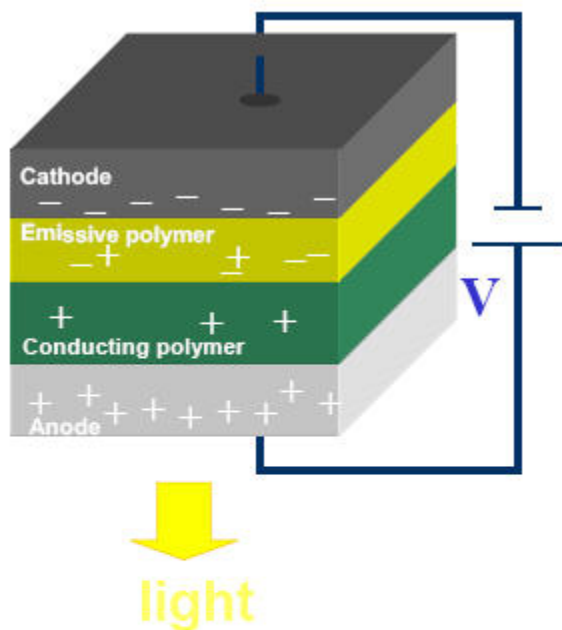
Electroluminescence in doped organic films



1.6 Organic light emitting diodes (small molecule devices)

An **exciton** is a bound electron hole pair (Coulomb correlated electron/hole pair). When dielectric constant of the material is very small, the Coulomb interaction between electron and hole become very strong and the excitons tend to be much smaller, of the same order as the unit cell, so the electron and hole sit on the same molecule. This is a **Frenkel exciton**, named after J. Frenkel. The probability of the hole disappearing (the electron occupying the hole) is limited by the difficulty of losing the excess energy, and as a result excitons can have a relatively long lifetime.

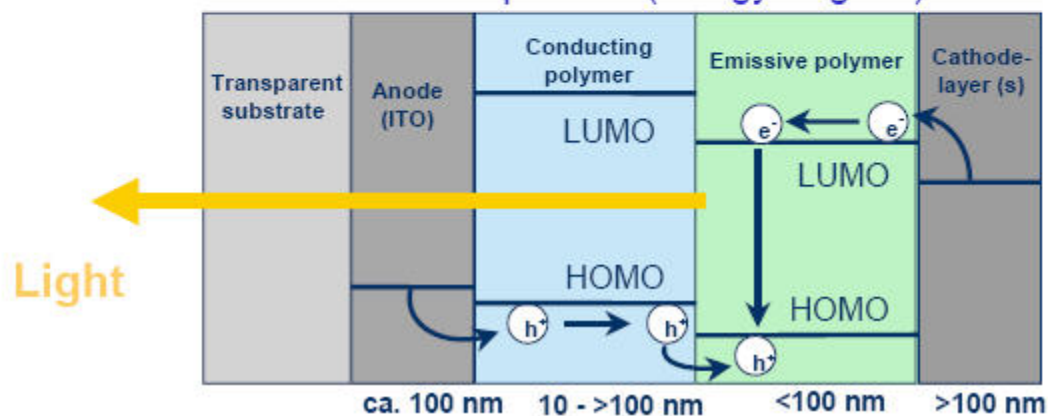
1.7 Polymer light emitting diodes (polymer devices)



OLEDs rely on organic materials (polymers or small molecules) that give off light when tweaked with an electrical current

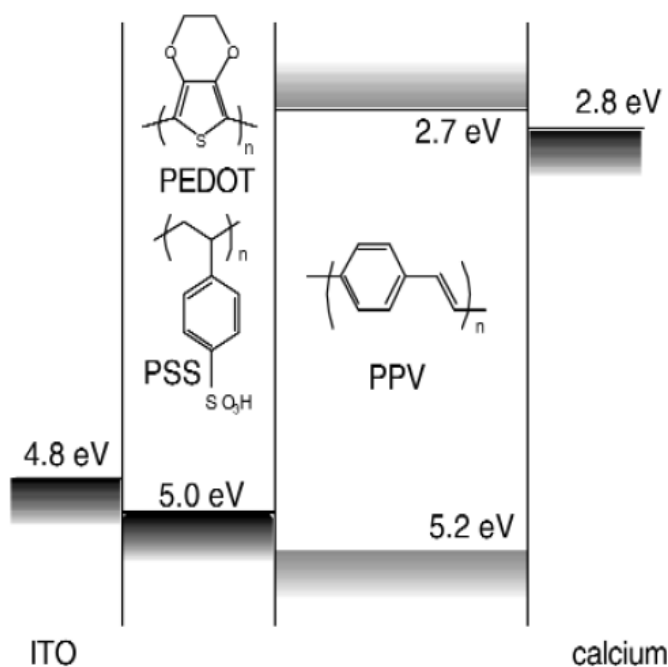
- Electrons injected from cathode
- Holes injected from anode
- Transport and radiative recombination of electron hole pairs at the emissive polymer

OLED device operation (energy diagram)



Ref.: H. Antoniadis, Osram

1.7 Polymer light emitting diodes (polymer devices)



Device structure:

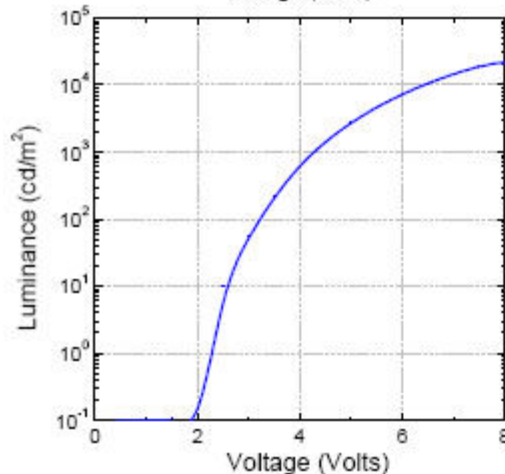
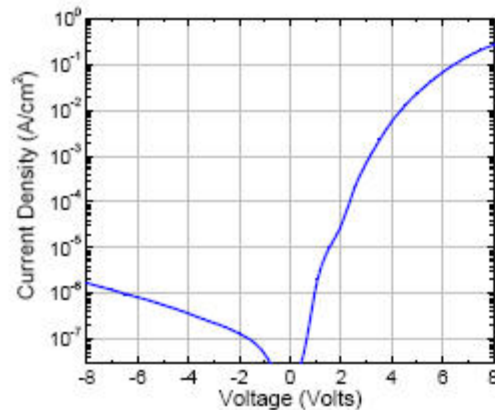
PEDOT:PSS as the
hole transport layer

PPV derivate as the
electron transport
and emitting layer.

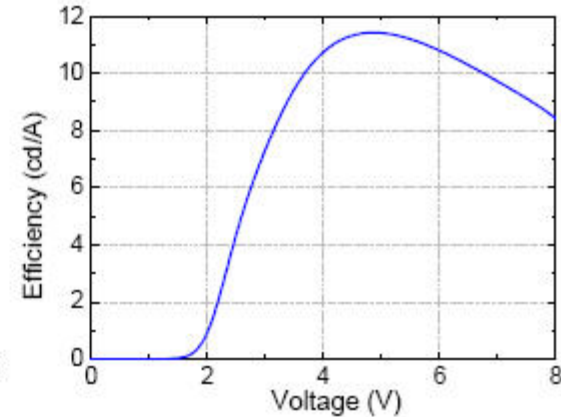
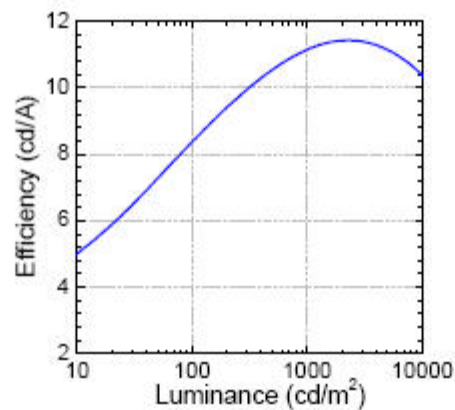
Ref.: R. Friend, Cambridge

1.7 Polymer light emitting diodes (polymer devices)

Luminance-Current-Voltage



Efficiency-Luminance-Voltage



LUMINANCE is the luminous intensity per unit area projected in a given direction

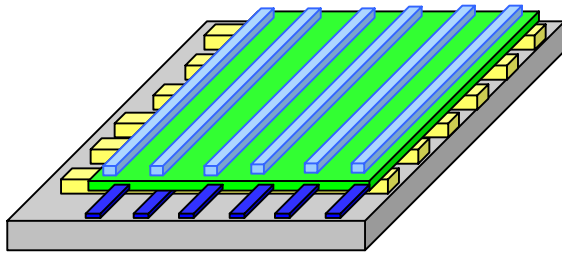
The SI unit is the candela per square meter (**cd/m²**), which is still sometimes called a **nit**

The **footlambert** (fL) is also in common use:
1 fL = 3.426 cd/m²

<http://www.resuba.com/wa3dsp/light/lumin.html>

Ref.: H. Antonidias, Osram

1.8 Passive versus Active Matrix Display Addressing

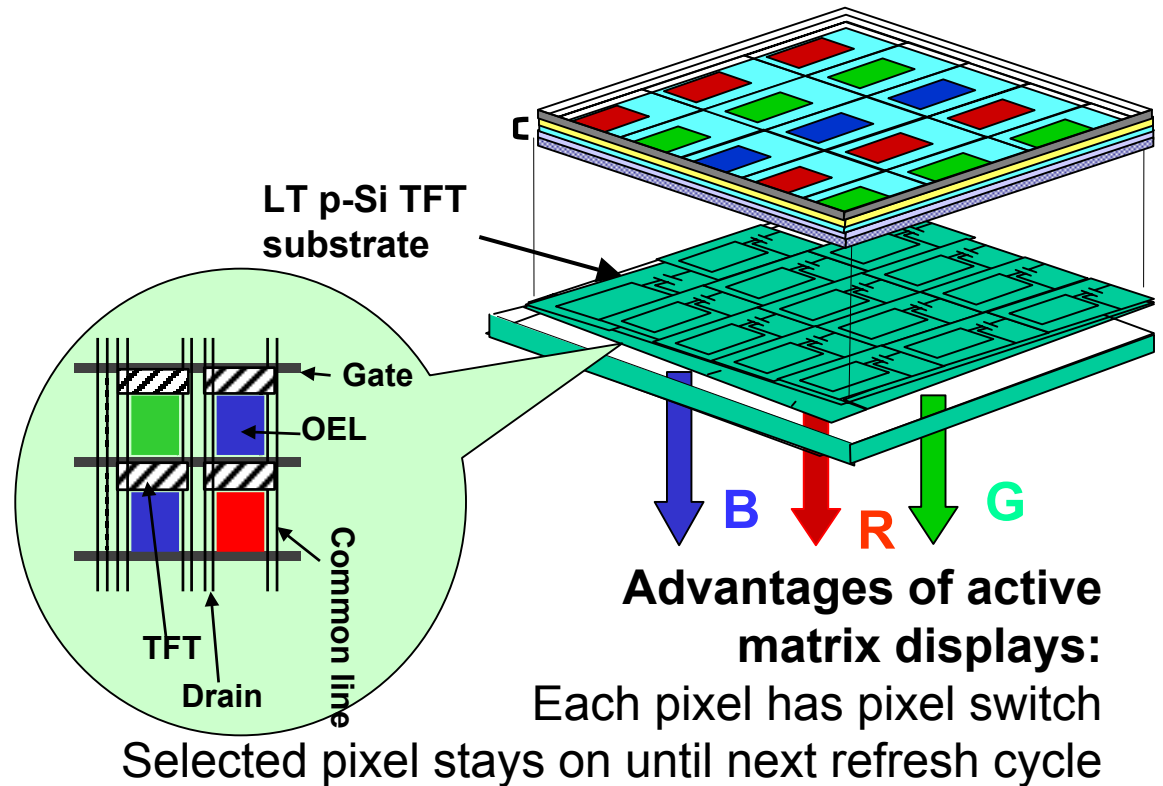


Advantages of passive matrix displays:

Matrixed Pixels
Line by Line scanning
Discrete drivers
Low Cost

Disadvantages

High brightness;
High current
Pixel cross-talk



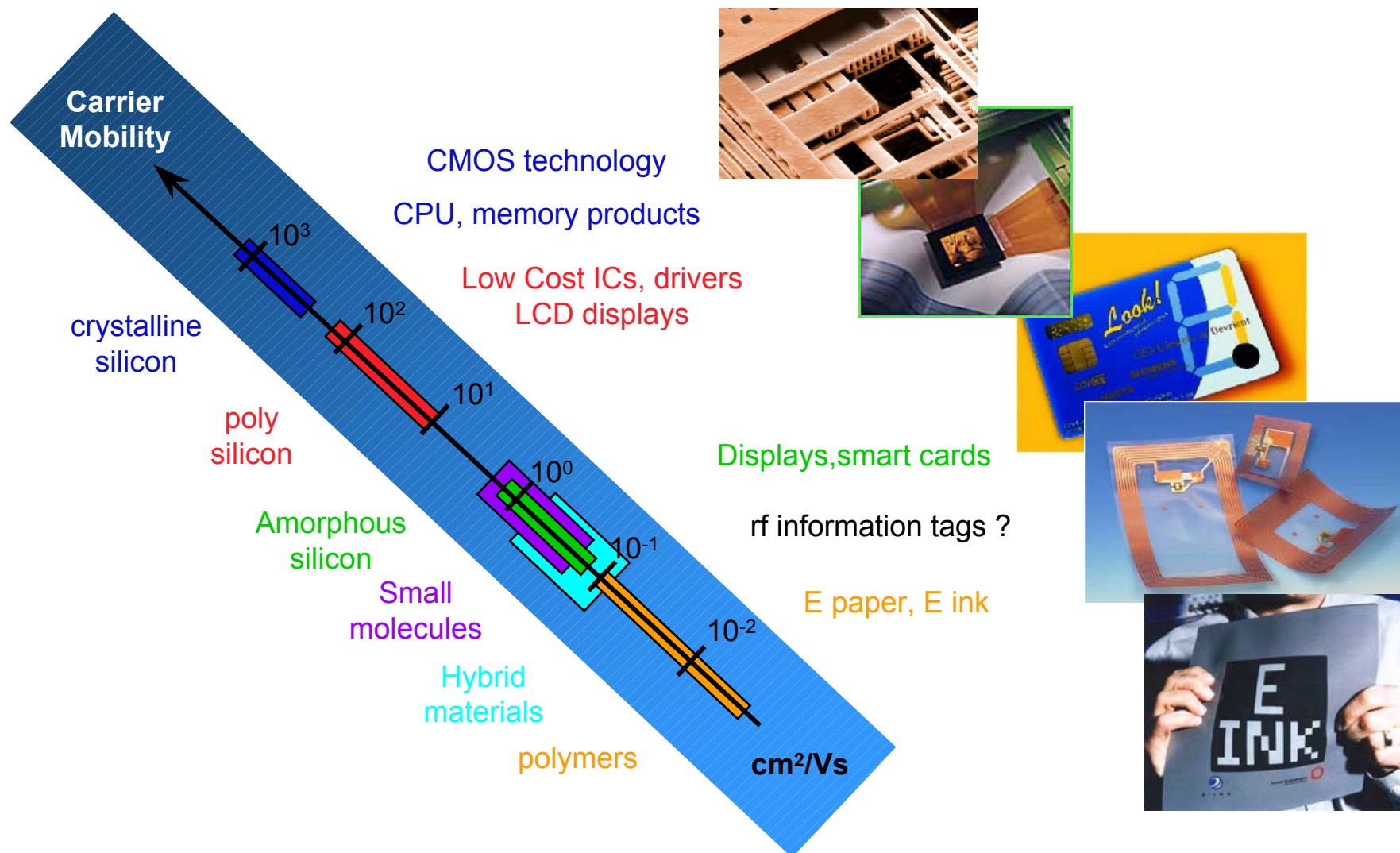
Advantages of active matrix displays:

Each pixel has pixel switch
Integrated drivers

Disadvantages:

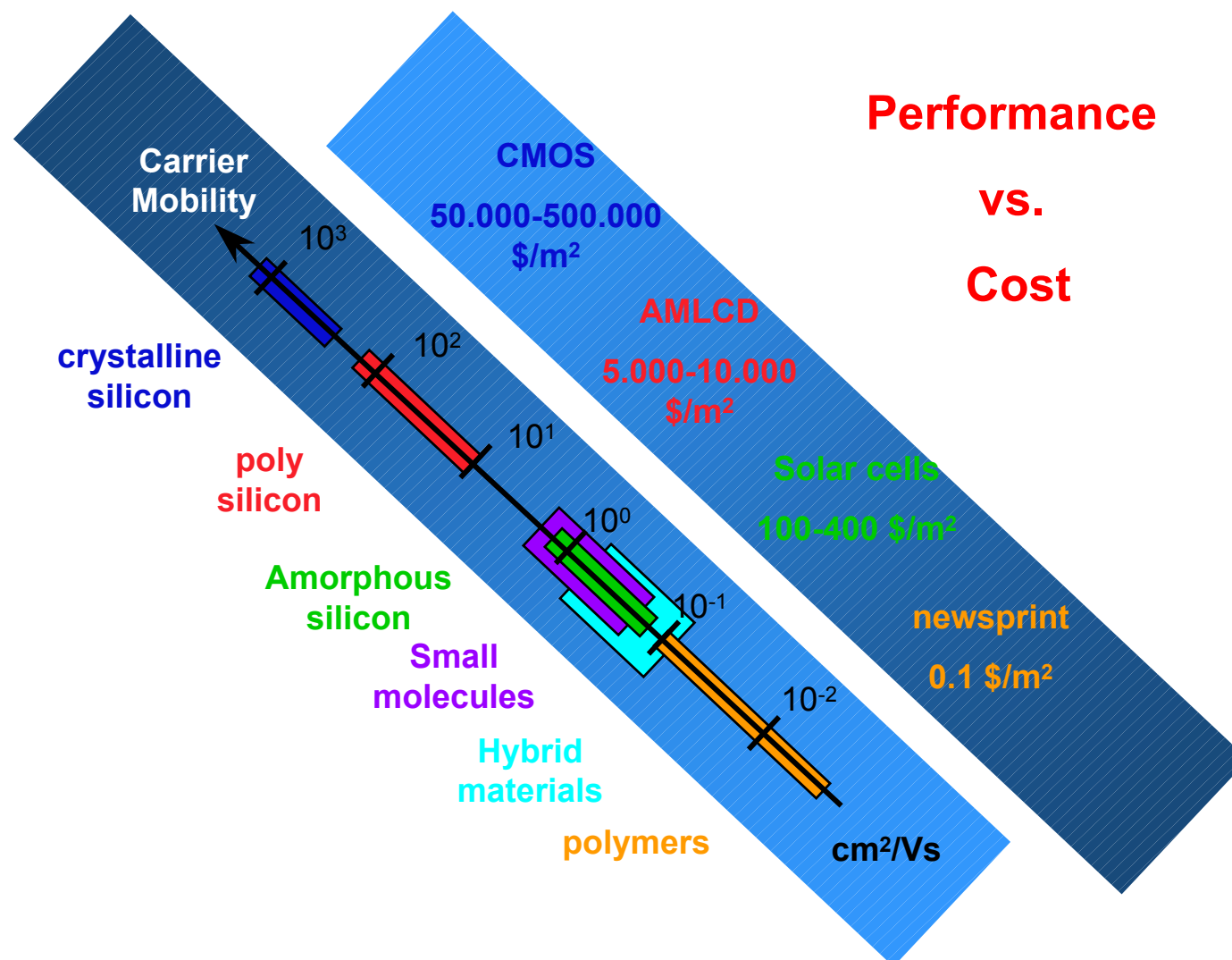
High cost
High quality TFTs required
Low area fill factor

1.9 Overview of thin film transistor technologies



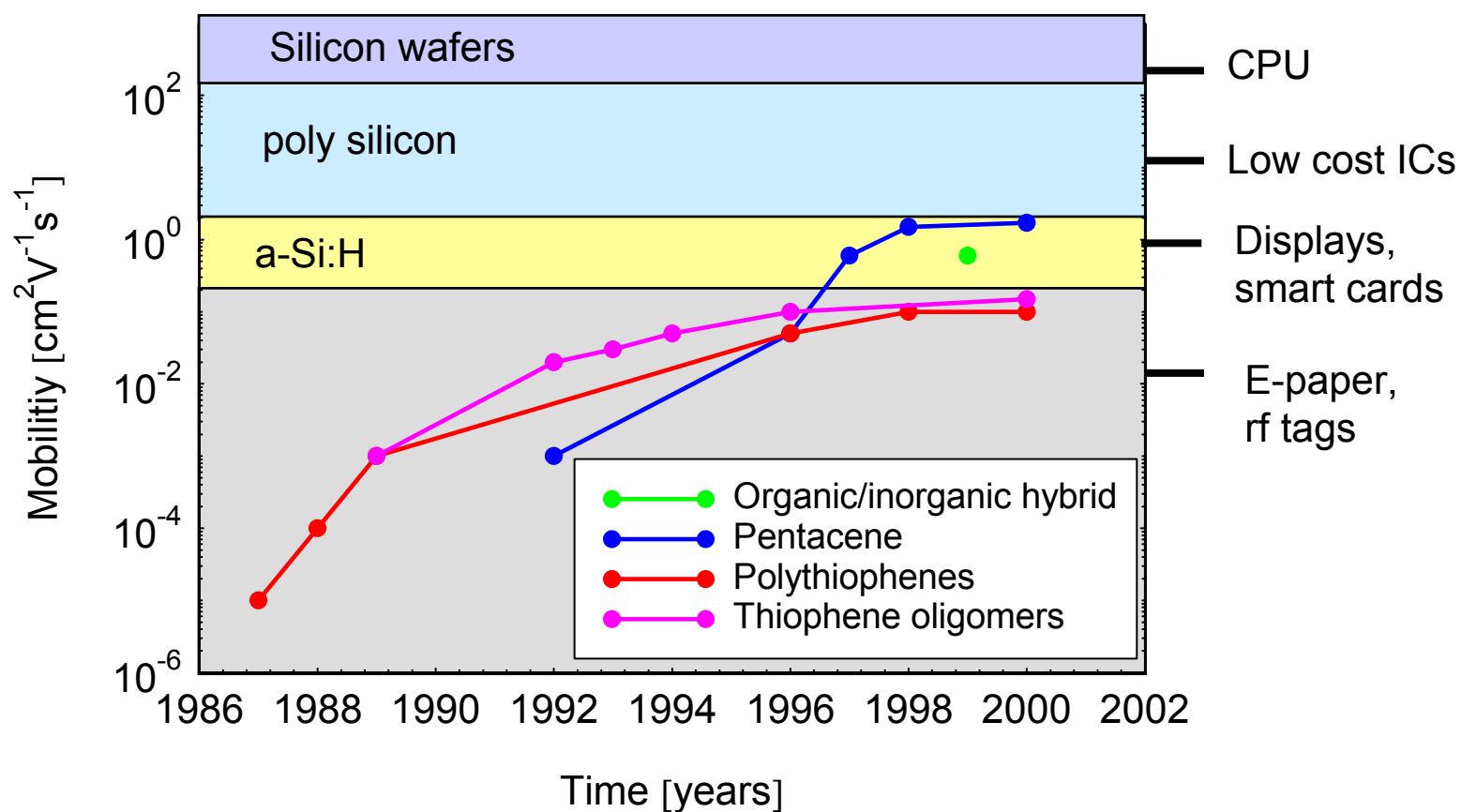
1.9 Overview of thin film transistor technologies

Materials, Devices and Applications



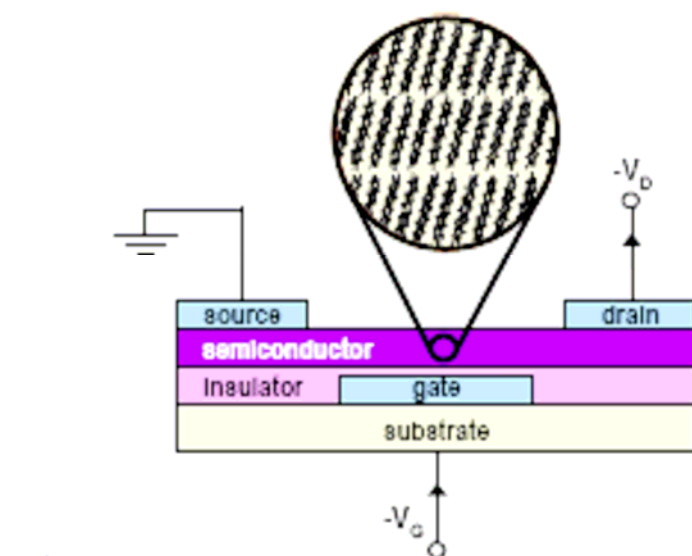
1.9 Overview of thin film transistor technologies

Organic thin film transistors



1.9 Overview of thin film transistor technologies

Organic thin film transistors



Charge carrier mobility is dependent on molecular order within the semiconducting thin film

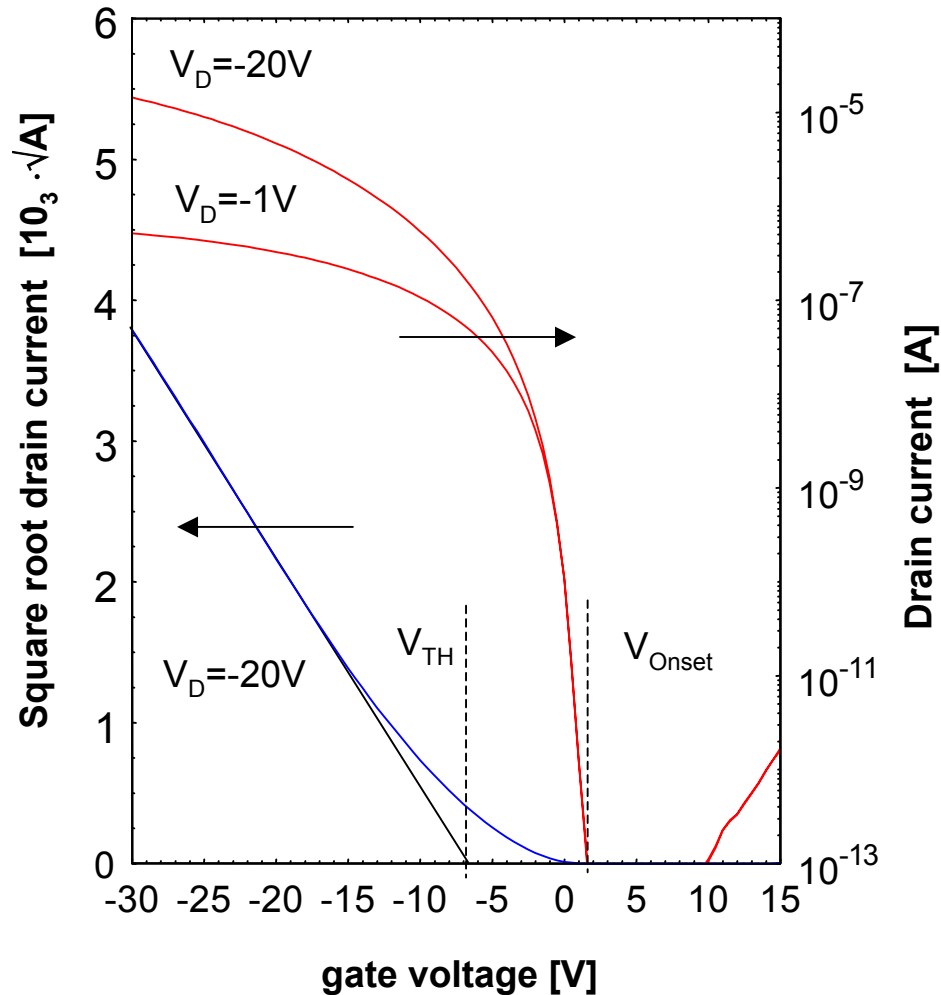
IMPROVED MOLECULAR ORDERING

↓
Larger grain sizes
Lower defect densities
↓
Enhanced mobility

Adapted from Dimitrakopoulos, et. al., IBM J. Res. and Devel. 45, 11 (2001).

1.9 Overview of thin film transistor technologies

Transfer characteristic of an pentacene TFT



- Transistors exhibit a pronounced subthreshold region.
- Variation of the onset of the drain current from run to run.
- The shift of the onset voltage is caused by unintentional doping.
- Onset of the drain current is typically positive.
- Threshold voltage is typically negative.

1.10 Summary

Organic semiconductors are of interest for a variety of applications like:
Anti Static Coatings, photo conductors

Most of the research in organic electronics is driven by the display industry. The goal is to develop low cost, low weight, low power consumption, large area and flexible displays.

In order to enter the market organic and polymeric displays have to compete against liquid crystal displays.

The performance of liquid crystal displays has been drastically improved and the cost has been drastically reduced for LCD displays.

Reflective displays (for example based on Polymer-Dispersed Liquid Crystals or electronic ink) are an interesting alternative to LCD if it comes to very large areas or low power consumption.

Organic and polymeric Light Emitting Displays are closest to applications in the field of organic electronics.

1.10 Summary II

In polymer LEDs a PPV derivate is used as the electron transport and emitting layer.

In organic LEDs Alq3 is used as the electron transport and emitting layer.

The performance of the organic and polymeric LEDs in terms of optical output power is close to the optical output of inorganic LEDs.

The optical spectrum of an LED has to be tailored towards the optical spectrum of the human eye, which is represented by a “Standard Observer (CIE Color standard)”.

Organic transistor are an emerging and new field of research. Typical applications are: displays, smart cards and radio frequency information tags (RFID tags).

Small molecule based transistors exhibit the highest performance of organic and polymeric transistors. The performance is comparable to the amorphous silicon transistors (standard transistors in display industry).

Most organic transistors are hole conducting devices.

References

Pope and Swenburg, Electronic Processes in organic crystals and polymers, 2 nd Ed., Oxford

Organic molecular crystals, E.A. Sininsh EA and V. Capek.

<http://researchweb.watson.ibm.com/journal/rd45-1.html>

(Special Issue of IBM journal on organic electronics)

<http://ocw.mit.edu/OcwWeb/Electrical-Engineering-and-Computer-Science/6-973Organic-OptoelectronicsSpring2003/CourseHome/>

(Organic optoelectronic lecture MIT)

<http://hackman.mit.edu/6976/overview.html>

(Seminar on Flat Panel Displays)